UCRL-JC-120505
PREPRINT

Overview of Nondestructive Evaluation Technologies

G. H. Thomas

This paper was prepared for submittal to
SPIE Nondestructive Evaluation of Aging Infrastructure
Oakland, CA
June 6-8, 1995

March 7, 1995

Lawrence Livermore National Laboratory

DISCLAIMER

Overview of Nondestructive Evaluation Technologies*

Graham Thomas

Lawrence Livermore National Laboratory
Livermore, California 94550

ABSTRACT

The infrastructure in the United States and the world is aging. There is an increasing awareness of the need to assess the severity of the damage occurring to our infrastructure. Limited resources preclude the replacement of all structures that need repairs or have exceeded their life times. Methods to assess the amount and severity of damage are crucial to implementing a systematic, cost effective approach to repair and/or replace the damaged structures. The challenges of inspecting aging structures without impairing their usefulness rely on a variety of technologies and techniques for nondestructive evaluation (NDE). This paper will briefly describe several nondestructive evaluation technologies that are required for inspecting a variety of systems and structures.

2. INTRODUCTION

The purpose of nondestructive evaluation is the prevention of potentially costly or destructive consequences from the failure of a material or component. The evaluations may be based on acoustics (sound); penetrating radiation (x- and gamma-rays, beta particles, protons, or neutrons); light (UV, infrared, and visible); electric and magnetic fields; or on a number of more esoteric possibilities. Because the inspections are performed on a vast array of structures and components, the evaluation methods vary greatly. NDE is not so much a single field as it is a synergism of physics and engineering disciplines. Specifically, NDE encompasses materials characterization, real-time inspection during manufacturing, flaw/damage detection in components, and inspection of assemblies for tolerances and alignment. NDE also can provide periodic in-service monitoring of flaw growth to determine the maintenance requirements and to assure the reliability and continued safe operation of the part. NDE increases the functionality of any component during its entire life .

Nondestructive evaluation techniques can be categorized into global, large area methods and local, high resolution methods. Global techniques such as acoustic emission, infrared imaging and ground penetrating radar offer rapid inspection of large structures. High resolution, localized techniques such as ultrasonics, x-ray, computed tomography, and eddy current better characterize the defects. A cost effective approach to inspecting a large structure such as bridge or an aircraft must entail first a global inspection such as infrared. The infrared inspect will identify possible defective areas. A second, high resolution technique for example ultrasonics, will confirm the presence of a defect such as a delamination and accurately locate and size the defect.

Each nondestructive evaluation procedure has advantages and limitations as listed in Table I. The proper selection and/or combination of methods optimizes the inspection. An optimized inspection has the best probability of detection with the minimum number of false calls. The selected techniques should also provide the required information at the lowest cost.

*Work performed under auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

3. NONDESTRUCTIVE EVALUATION TECHNIQUES

3.1 Ultrasonic Inspection

Ultrasonic nondestructive evaluation probes materials with high-frequency sound waves to measure their properties and locate defects. Pulses of ultrasonic energy are launched into the material and detected by specially designed and carefully placed transducers. These pulses are altered as they propagate through the material due to attenuation, reflection, and scattering. The output pulse (the detected signal) is displayed, processed, and interpreted in terms of the internal structure of the object under investigation based on its relation to the input pulse. Ultrasonic inspection searches for flaws in metallic and non-metallic (e.g., composites) materials, viz., cracks, voids, delaminations; however, it can also ascertain grain size, measure elastic moduli, map residual stresses, evaluate bond quality, and analyze surface characteristics. Frequencies employed are typically in the 20 KHz to 1 GHz range with resolutions approaching a few micrometers.

Ultrasonics is a well established method for laboratory, production plants, and field inspections. Immersion system, including squirters are found in laboratories and on production line. Contact ultrasonic inspection, including computer controlled scanners, are applied routinely to field inspections.

3.2 Liquid Penetrant & Magnetic Particle Inspection

Liquid penetrant and magnetic particle testing inspects materials and fabricated parts to test for surface and near surface cracks and defects. The liquid penetrant method which is generally conducted on nonporous materials consists of applying a penetrating fluorescent or visible dye liquid which enters the discontinuity on the surface. The penetrant accentuates the surface defect so that it is more visible.

Magnetic particle method detects discontinuities in magnetic materials. To perform the inspection, the test object is properly magnetized and finely divided magnetic particles are applied to the surface. A discontinuity creates a leakage field forming a visible indication in the magnetic particles. Both methods routinely inspect bulk materials, welds, and critical areas of structures. They can also inspect raw materials in the early stages of the forming process for detecting fabrication defects before further value is added.

3.3 Eddy Current/Electromagnetic Inspection

Eddy current testing evaluates material properties and defects by probing the material with electromagnetic waves using coils and/or magnetic fields. The electromagnetic field interacts with discontinuities in the electrical conductivity and/or magnetic properties of the material. The response of the eddy current or magnetic sensor can be related to defects and internal structure.

Eddy current methods are widely applied to conductive materials while magnetic methods are restricted to ferromagnetic alloys. Eddy currents penetrate a distance related to the frequency of the interrogating electromagnetic wave and are generally limited to depths of 6-8 mm in metals. This method is noncontacting and can inspect large amounts of material quickly.

3.4 Infrared Imaging

Infrared imaging (IR) remotely senses and records surface temperatures and temperature gradients across a field of view. IR can be used wherever heat is generated in a part or assembly or in the manufacture or conditioning of a part. Temperatures from -20 to 1500 degrees C can be measured and imaged to within 0.1 to 0.5 degree accuracy. The infrared imaging instrumentation is applied in both laboratory and field environments. The equipment can be used to monitor laser, electron beam and gas tungsten welding, and to determine the temperature of the base material in a welded assembly. It can also be used to measure the temperature of hot pressings, of material inside furnaces, and of material that is being heated by microwaves. Materials subjected to steady-state mechanical energy, such as fatigue loads or low-amplitude vibrations, are characterized by localized temperature gradients near the affected regions. This phenomenon can be used to locate impact or service produced damage and fabrication imperfections in fiber reinforced composites. In the field infrared imaging has sensed and displayed delaminations in bridge decks, buried land mines, and corrosion damage in aircraft.

3.5 Radiographic Testing

Radiography is a nondestructive technique for inspecting the internal structure and composition of an object using penetrating radiation (i.e. X-rays, gamma rays, beta particles, neutron or proton beams). Radiography generates an image of internal structure and defects. Quantitative image processing allows for measuring materials characterization, assuring assembly integrity, and determining dimensional measurements. Advanced imaging systems provide increasingly sophisticated capability for field inspection requirements. Radiographic applications fall into two distinct categories: single materials or components and assembly inspection. Radiography is particularly appropriate for the detection of cracks, voids and material contaminants. It is frequently and routinely used to inspect the quality of welds and brazes where both ASTM and ASME codes are available. Assembly inspection centers on internal structure and composition. Relative positioning of components and dimensional measurements are typical inspection goals. Radiography can be used as a materials characterization tool, a quality control tool, and as an in-service-inspection technique.

Radiographic inspection are performed in the field with portable x-ray sources and isotopes. The field detector is usually film but digital images can be captured with scintillating glass and a video camera. X-ray energies range from small sources up to transportable 9 Mev linear accelerators for large structures. Examples of applications are aircraft, bridge structures, rocket motors, and ships.

3.6 Computed Tomography

Computed tomography (CT) measures volume densities of materials and provides pictorial views of the internal structure of materials and fabricated parts. CT is related to conventional X-ray radiography. Radiography produces a shadowgraph of an object, with the internal structure of an object compressed on to the plane of the film. In computed tomography, the object being investigated is translated and rotated in the path of the radiation, with transmission measurement made at each position. The data are then reconstructed into images using computer algorithms. Multiple slices through the object can be reconstructed to generate a three dimensional view of internal structure.

Generally, the smaller the object and lower the atomic number, the softer the radiation which is required and higher the resolution of the tomogram. Computed tomography images can be obtained in the energy range of 1 KeV - 9 MeV with corresponding resolutions of tens of micrometers to a few millimeters. CT can usually be performed on the same structures that traditional x-ray is.

3.7 Ground Penetrating Radar

Ground Penetrating Radar images subsurface objects and defects with high frequency electromagnetic energy. An antenna radiates a short duration pulse which travels through the media until it is reflected back by a change in the media. A profile of the reflection is generated and displayed by a computer system. A cross sectional view of structure beneath the scan path of the antenna is displayed. Thus depth and location information is provided.

Ground Penetrating Radar finds and maps buried objects, soil profiles, rebar in concrete, and delaminations in road beds. Data acquisition can be done at relatively high rate so that large areas can be scanned quickly. For example, the antenna could be mounted on a vehicle and the radar data could acquired as the vehicle moved along the highway.

3.8 Signal And Image Processing

Most NDE techniques produce results which can be represented as a 2-dimensional image. The usefulness of these images is fundamentally dependent on the capability to extract quantitative information from the data set used to produce the image. A broad range of signal and image processing codes enhance images generated by radiographic, ultrasonic, and computed tomography inspections.

The application of signal processing techniques to NDE data is particularly useful in making quantitative determination of material density, thickness, elemental makeup, and precise determination of flaw size or location. Inspection reports include statistical information regarding material uniformity or composition as well as precise dimensional information. Dimensional measurements can now be made on image detail as small as 10 to 15 microns and as large as 16" and material density changes as small as 1% detected.

4. SUMMARY

Nondestructive evaluation is a valuable technology for assessing damage to the aging infrastructure. A wide range of techniques are available to characterize materials and detect defects in a variety of components. The techniques can be categorized into global, large area methods and local, high resolution methods. Global techniques such as acoustic emission infrared imaging and ground penetrating radar offer rapid inspection of large structures. High resolution, localized techniques such as ultrasonics, x-ray, computed tomography, and eddy current better characterize the defects. Applications of the appropriate methods will help assess the condition of structures and allow cost effective solutions to repair and/or replace programs. As deterioration progresses on our infrastructure it will become increasingly important to accurately determine the remaining life and avoid catastrophic failures.

This paper provides a brief description of several nondestructive evaluation techniques that have application to assessing the condition of our aging infrastructure. Particular emphasis is on techniques which apply to maritime applications, bridges and highways, aircraft, airports, aerospace hardware, civil structures, dams, railroads, and utilities. More detailed descriptions are found in the papers presented at the conference.

Table I - Capabilities of NDE Methods

Method	Typical Inspection Goals	Typical Applications	Advantages	Limitations
Radiography	Cracks, voids, inclusions, porosity, material uniformity, assembly integrity, alignment of components, joint integrity	Castings, forgings, machined parts, welds, foams, electronic components, composites,	Detects internal flaws and conditions; useful on wide range of geometry's and materials; quantitative as well as qualitative; permanent record	High cost, cannot detect tight laminar flaws or very tight cracks, 2D image of 3D structure.
Ultrasonics	Cracks, disbonds, porosity, inclusions, delaminations, corrosion, thickness variations,	Welds , brazes, adhesive bonds, diffusion bonds, composites, tubing & piping,	Fast, best at crack detection and sizing; can be automated; equipment relatively inexpensive	Difficult to apply to complex shapes; generally requires water or other sound couplant; interpretation sometimes difficult
Computed Tomography	Cracks, voids, inclusions, porosity, material uniformity, assembly integrity, alignment of components,	Castings, forgings, machined parts, welds, foams, electronic components, composites,	Detects internal flaws and conditions in three dimensions; useful on wide range of geometries and materials; quantitative as well as qualitative; permanent record	High cost, cannot detect tight laminar flaws or very tight cracks; long inspection times
Magnetic Particle	Cracks, laps, voids, delaminations and seams.	Ferro-magnetic castings, forgings, extrusions	Detects near sub-surface flaws as well as those open to surface; portable, easy to implement	Applicable to Ferro-magnetic materials only; flaws must be near surface; requires surface preparation,
Infrared Imaging	Detection of minute temperature differences which correlate to material defects or component performance.	Multi-layered circuit boards, detect corrosion in aircraft skins monitor EB, laser and gas-tungsten welding, map delaminations in bridge decks	Non contact, detects conditions which affect heat transfer or generation in materials, real-time inspection capability	Equipment costly, results affected by ambient temperature conditions and surface emissivity variations
Liquid Penetrant	Cracks, voids (porosity), gouges, seams	Weldments, forgings, critical machined surfaces, castings, components subject to fatigue or stress-corrosion cracking	Inexpensive; easy to implement; portable; easily interpreted.	Flaws must be open to surface; Requires immersion of part in oil- or water-based penetrant; depth of flaw difficult to estimate, operator dependent
Eddy Current	Cracks, voids, variation in alloy composition or heat treatment, wall thickness, dimensions	Tubing, alloy sorting, coating thickness measurements	Readily automated, portable	Geometry sensitive; shallow penetration; affected by conditions which change conductivity, difficult to interpret